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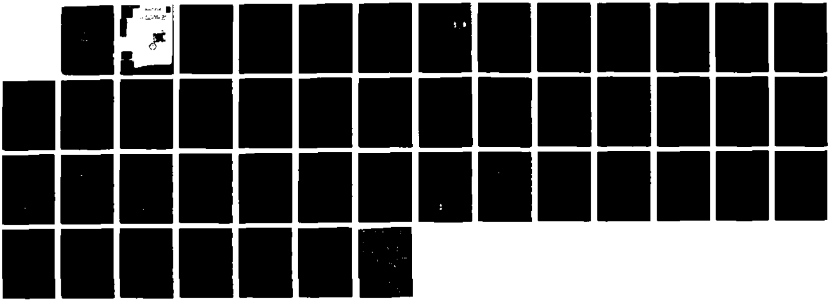

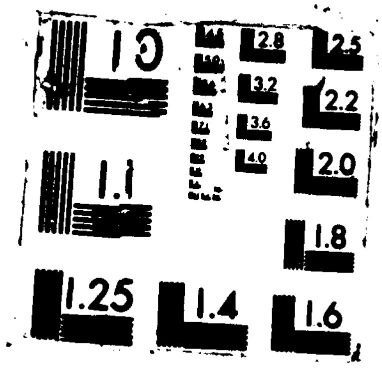
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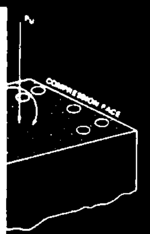

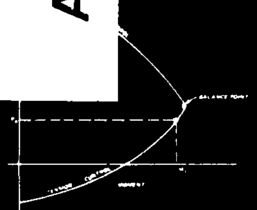

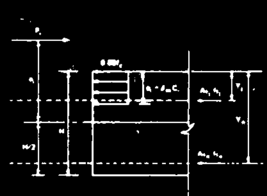

COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

INSTRUCTION REPORT ITL-87-2

USER'S GUIDE FOR CONCRETE STRENGTH INVESTIGATION AND DESIGN (CASTR) IN ACCORDANCE WITH ACI 318-83

by

Clifton C. Hamby, William A. Price III

Information Technology Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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Final Report

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PROGRAM INFORMATION

Description of Program

CASTR, called X0067 in the Conversationally Oriented Real-Time Program-Generating System (CORPS) library, is a general-purpose computer program for the strength theory analysis or design of reinforced concrete beams or columns, in accordance with ACI Code 318-83. It is intended to be an easy-to-use program.

Coding and Data Format

CASTR is written in FORTRAN and is operational on the following systems:

a. US Army Engineer Waterways Experiment Station (WES) and Division office's Honeywell DPS/8.

b. District office's Harris 500.

c. Cybernet Computer Service's CDC CYBER 175.

d. Microcomputers running under MS-DOS or PC-DOS.

Data must be in a prepared data file with line numbers. Output comes directly back to the terminal. If the program is being run on mainframe time-sharing, the terminal must be a Tektronix 4014. If it is being run on a microcomputer, the display must be IBM Color Graphic or compatible.

How to Use CASTR

Directions for accessing the program on each of the systems is provided below. It is assumed that the user can sign on the appropriate system before attempting to use CASTR. In the example initiation of execution commands below, all user responses are underlined, and each should be followed by a carriage return.

Honeywell Systems

After the user has signed on the system, the system command FORT brings the user to the level to execute the program. Next, the user issues the run command

```
**   RUN WESLIB/CORPS/XØØ67,R
```

to initiate execution of the program. The program is then run as described in this user's guide. The data file should be prepared prior to issuing the RUN command. An example initiation of execution is as follows, assuming a data file has previously been prepared:

```
     HIS TIMESHARING ON Ø3/Ø4/81 AT 13.3Ø1 CHANNEL 5647
     USER ID - RØKACASECON
     PASSWORD - WHERE/ARE/YØU?
     *FORT
**   *RUN WESLIB/CORPS/XØØ67,R
```

CYBERNET System

The log-on procedure is followed by a call to the CORPS procedure file

OLD,CORPS/UN=CECELB

to access the CORPS library. The file name of the program is used in the command

** BEGIN,,CORPS,XØØ67

to initiate execution of the program. An example is:

```
84/12/Ø5.  16.41.ØØ.  AC2F5DA
EASTERN CYBERNET CENTER SN9Ø4 NOS     1.4/531.669/2ØAD
FAMILY:  KOE
USER NAME:  CEROXX
PASSWORD -
XXXXXXXX
TERMINAL:  23, NAMIAF
RECOVER/CHARGE:  CHARGE,CEROEGC,CEROXX
$CHARGE
12.49.07.  WARNING

11/29 FOR IMPORTANT INFO TYPE EXPLAIN,WARNING.
OLD,CORPS/UN=CECELB
** /BEGIN,,CORPS,XØØ67
```

Harris 500 System

The log-on procedure is followed by a call to the program executable file, with the user typing the asterisk and file description

** *CORPS,XØØ67

to initiate execution of the program. An example is:

```
"ACOE-ABLESVILLE (H500 V3.1)"
ENTER SIGN-ON
1234ABC,STRUCT

**GOOD MORNING STRUCTURES, IT'S 7 DEC 84 Ø8:33:12
AED HARRIS 500 OPERATING HOURS 0700-1800 M-S
** *CORPS,XØØ67
```

How to Use CORPS

The CORPS system contains many other useful programs which may be catalogued from CORPS by use of the LIST command. The execute command for CORPS on Honeywell system is:

```
RUN WESLIB/CORPS/CORPS,R
ENTER COMMAND (HELP,LIST,BRIEF,MESSAGE,EXECUTE, OR STOP)
*?LIST
```

on the Cybernet system, the commands are:

```
OLD,CORPS/UN=CECELB
CALL,CORPS
ENTER COMMAND (HELP,LIST,BRIEF,MESSAGE,EXECUTE, OR STOP)
*?LIST
```

Microcomputers

Special instructions for the microcomputer version are in a file named XØØ67.DOC on the program diskette.

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User's Guide for Concrete Strength Investigation and Design (CASTR) In Accordance with ACI 318-83

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FIELD	GROUP	SUB-GROUP	CASTR (Computer Program) (LC) Computer-Aided Design (WES) Concrete Products--Evaluation (LC) Structures--Computer Programs (LC)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Program CASTR is versatile in that its capabilities extend from design of new concrete structures in accordance with ACI Code 318-83 to investigation of already existing designs. Its analysis is based on the rectangular stress block described in Section 10.3 of the ACI Code.

The design procedure is computer-aided rather than automatic and computes the minimum reinforcement required for a given width and depth, and displays the resulting interaction diagram. The program also computes and prints the minimum effective depth of a given section which satisfies strength requirements and steel ratio requirements without compressive reinforcement.

The investigation procedure shows interaction diagrams and calculates compliance with ductile failure criteria.

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SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM	PROGRAM NO.
User's Guide for Concrete Strength Investigation and Design (CASTR) in Accordance with ACI 318-83	713-F3-R0067

PREPARING AGENCY US Army Engineer Waterways Experiment Station, Information Technology Laboratory, PO Box 631, Vicksburg, MS 39180-0631

AUTHOR(S)	DATE PROGRAM COMPLETED	STATUS OF PROGRAM: PHASE	STATUS OF PROGRAM: STAGE
C. C. Hamby (LMKED-DS) and W. A. Price III (WESKA-E)	October 1985	Operational	

A. PURPOSE OF PROGRAM

To perform investigation or design of concrete beams or columns in accordance with ACI Code 318 for nonhydraulic structures.

B. PROGRAM SPECIFICATIONS

Written in FORTRAN IV using the Graphics Compatibility System (GCS). The CORPS time-sharing library file name is X0067.

C. METHODS

Strength analysis for investigation or design of rectangular cross sections of nonhydraulic structures subjected to axial load plus uniaxial flexure. Analysis is based on the rectangular stress block approximation described in Section 10.2.7 of ACI 318-83.

D. EQUIPMENT DETAILS

Tektronix 4014 terminal, if graphics output is desired, otherwise, any ASCII time-sharing terminal.

E. INPUT-OUTPUT

Input is from a data file; output is to a Tektronix 4014 graphics terminal or regular printing terminal.

F. ADDITIONAL REMARKS

Input data are prepared the same as for program 713-F3-RO 066, "CSTR-Concrete Strength Investigation and Design of Hydraulic Structures (X0066)." Differences between the two programs lie only in the stress block depth and other parameters. Call WES, (601) 634-2300 or FTS 542-2300 for more information.

Preface

The computer program described in this user's guide was derived from program CSTR developed as a part of the work by the Engineering Applications Office (EAO), formerly Computer-Aided Design Group, Automation Technology Center, US Army Engineer Waterways Experiment Station (WES), in support of the Computer-Aided Structural Design (CASD) Committee of the US Army Engineer Division, Lower Mississippi Valley (LMVD). Funds for program CSTR were provided by LMVD as part of WES, Information Technology Laboratory (ITL), engineering analysis support. Funds for the CASTR derivation and report were provided by the Computer-Aided Structural Engineering (CASE) Project.

Mr. V. M. Agostinelli of LMVD was chairman of the CASD Committee during this work. The theoretical development for program CSTR was performed by Mr. Clifton C. Hamby, formerly of the EAO and presently of the US Army Engineer District, Vicksburg (LMK). Programming was by Mr. Hamby, assisted by Mr. William A. Price III, Chief, EAO. Preparation of program CASTR was by Mr. Price as were the program verification calculations. The work was performed under the direction of Mr. Paul K. Senter, Supervisor and Civil Engineer, ITL, with overall supervision by Dr. N. Radhakrishnan, Acting Chief, ITL. Ms. Gilda Miller, Editor, Information Products Division, ITL, prepared the material in the report for final publication.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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Contents

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
inches	2.540	centimetres
kips (force)	4.448222	kilonewtons
kip-feet (force)	1355.818	newton-metres
kip-inches	112.9848	newton-metres
kips (force) per square inch	6.894757	megapascals
pounds per square inch	6.894757	kilopascals

USER'S GUIDE FOR CONCRETE STRENGTH INVESTIGATION AND DESIGN (CASTR) IN ACCORDANCE WITH ACI 318-83

Introduction

1. A computer program, Program CASTR, has been developed by the US Army Engineer Waterways Experiment Station (WES) Information Technology Laboratory, formerly Automation Technology Center, that can be used for design of or investigation of rectangular concrete members by the strength design method described in Section 10.3 of ACI Code 318-83.* Program CSTR ("C-STAR") is in compliance with the guidance contained in Engineer Technical Letter ETL 1110-2-265.** It utilizes a generalized equation to obtain the axial force and moment capacity of any rectangular concrete section, reinforced or not, in any pattern (paragraph 13). This approach allows for solution of a wide variety of problems and loadings, such as singly or doubly reinforced beams, columns, beam-columns, tension members, etc.

Assumptions

2. The fundamental assumptions used in the development of program CASTR are summarized below. More details on these assumptions are included in paragraphs 10 through 16. Figure 1 is provided to further complement the following discussions.

- a. The cross section is rectangular.
- b. The reinforcement may be in any general pattern with no more than 20 rows of steel.
- c. The loading may consist of a uniaxial moment and an axial load. The axial load can be tension, compression, or zero.
- d. ACI 318-83 criteria on stress and strain are used to compute moment and load capacities.
- e. Reinforcement, in investigation or design, is assumed to be capable of developing stresses up to F_y . The user's attention is directed to American Concrete Institute (ACI) requirements on the tie steel necessary for making compression bars effective in developing stress.

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* American Concrete Institute, "Building Code Requirements for Reinforced Concrete (ACI 318-83)."

** Engineer Technical Letter 1110-2-265, "Strength Design Criteria for Reinforced Concrete Hydraulic Structures," 1981 (Sep).

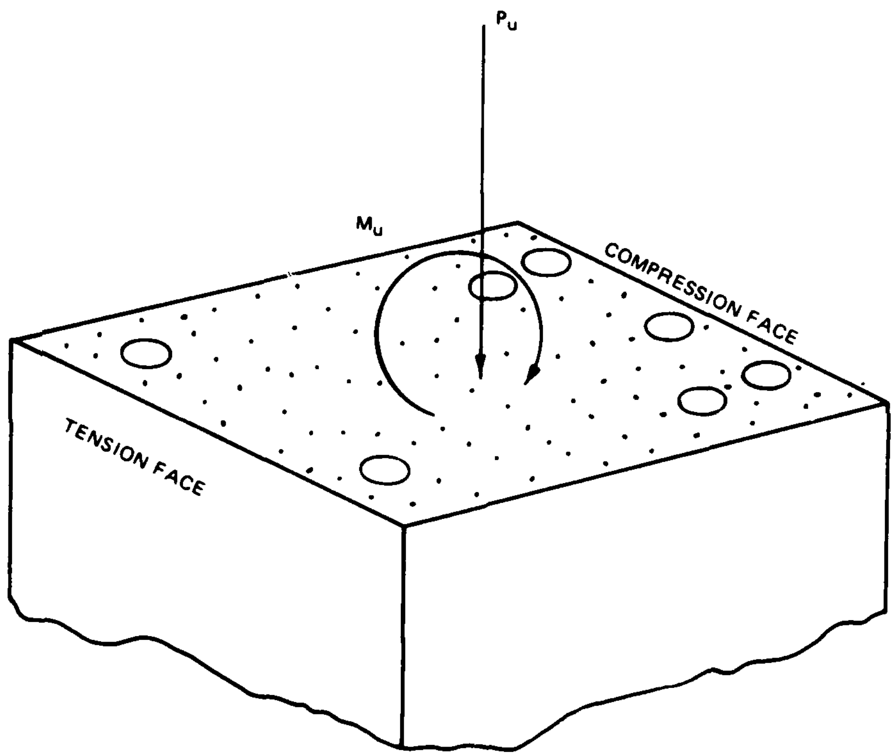


Figure 1. Applied load sign convention

f. The program does not check concrete sections for general compliance with the ACI Code, however.

Design Capability

3. Program CASTR will compute the area of steel required for a beam or for a column having a fixed width and depth. The program will not design the size of a member since, in most cases, selection of member sizes requires design judgment. Procedures for describing steel patterns and computing the required area of steel are considerably different for beams when compared to columns. As a result, the input data for beam and column design must be prepared in a slightly different manner. Paragraphs 17 through 19 give more details on these differences.

Beams

4. In beams, bars are usually defined as rows of tension and compression steel with ductility also an important consideration. Therefore, for beam design the user is required to describe spacing criteria for tension steel, spacing criteria for compression steel, and limits on steel ratios. CASTR

checks the need for tension steel and adds what is required, beginning with the outermost layer, progressing inward (Figure 2). Likewise, the need for compression steel is examined and added, if required, progressing from outer to inner layers. A sufficient amount of compression steel is added to satisfy steel ratio limits on tension steel (0.75 P_b , for example).

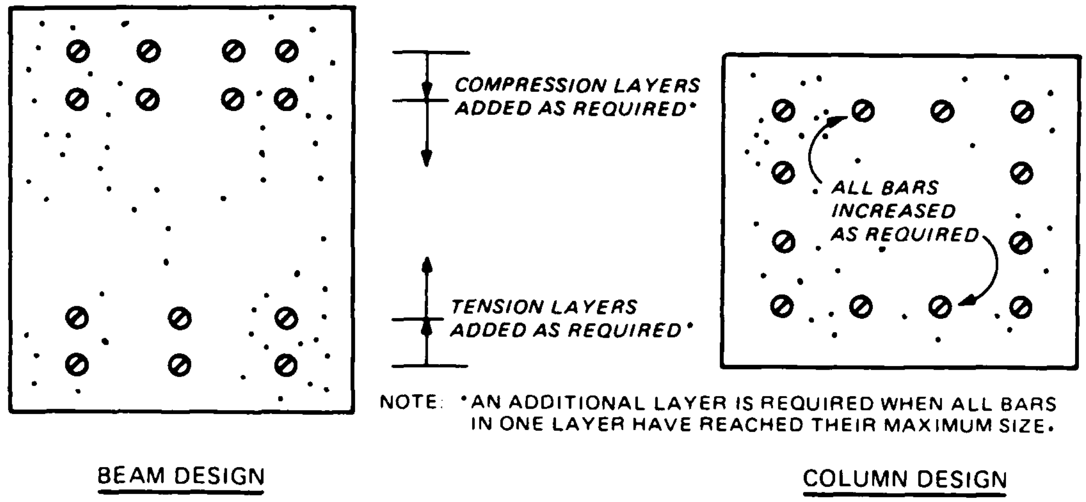


Figure 2. Reinforcement design procedure

Columns

5. In column design, bars are rarely described as being in tension or compression layers; rather, all bars are described in a set pattern. Also, since ductility is normally not a consideration in column design, the user is required to describe a desired bar pattern and the minimum acceptable bar size. The program then computes the size of bars with the described pattern necessary to carry the loads. Slenderness effects are not considered and bars are assumed to be tied in accordance with the ACI Code.

Investigation Capability

6. The capabilities of the program extend beyond design into investigation checking procedures.

Beams and columns

7. The program makes no distinction between beams and columns with its investigation procedure. Height and width of a rectangular section, as well as bar areas and locations, are defined by the user. The program then computes the strength of the section and compares this calculated strength with

applied loads. CASTR displays the strength of a section in the form of an interaction diagram; therefore, use of this program requires an understanding of the principles of interaction diagrams. A brief explanation of interaction diagrams and their use is provided in paragraphs 10 through 16.

Ductility check

8. Limits on steel ratios are normally thought of as a means to ensure ductile behavior and are discussed herein as checks on ductility. In fact, steel ratio limits in Corps criteria ensure both ductility and crack control. When the program is used for investigation purposes, the user must input a maximum allowable steel ratio. In most cases of beam design and in some cases of column design, it is important to stay within this maximum limit; therefore, the program checks for satisfaction of ductility requirements in the described section. In some cases of column investigation, the user may choose to ignore the program's check on ductility, also maximum steel ratios set by the ACI for columns are not checked.

Theoretical Background

9. Making full use of program CASTR requires an understanding of interaction diagrams and how they are used.

Interaction diagrams

10. An interaction diagram is plotted on a graph with axial force as the vertical axis and moment as the horizontal axis. An interaction diagram ordinarily is a plot of the moments and axial loads which cause a concrete member to fail.

11. Figure 3 shows an axial load of value P_a acting together with a moment of value M_a and causing a member of specified size to fail. The diagram, then, represents a failure envelope, since points falling inside the curve do not cause failure and those falling on or outside the curve do cause failure.* A reinforced concrete member is made of two differently behaving materials, steel and concrete, and the equations which define failure depend on whether the steel yields or the concrete crushes. The tension control range represents those axial loads and moments which cause the section to fail

* The term failure is used in discussion; however, failure is actually defined by the ACI as occurring when concrete strains reach 0.003.

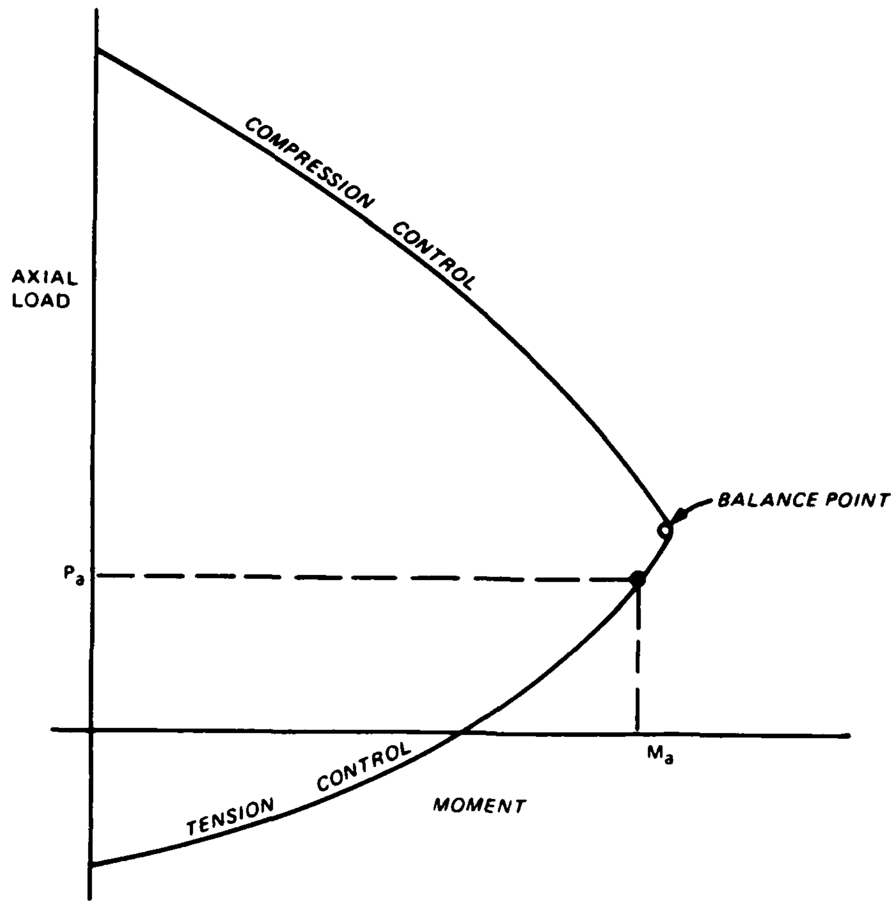


Figure 3. Interaction diagram

because the steel yields (Figure 3). Likewise, the compression control range represents those combinations of axial loads and moments which cause the member to fail by crushing of the concrete. The axial load and moment which cause simultaneous failure of steel and concrete is the balance point.

Stress-strain assumptions

12. Strains are zero at the neutral axis and vary linearly from the neutral axis to a maximum value of 0.003 at the extreme fiber. The compressive stresses in the beam are approximated by a rectangular stress block $0.85\ f'_c$ in magnitude and $\beta_m C$ high. Throughout this report, the term β_m of ETL-265 and β_1 of ACI Code 318-83 should be considered interchangeable.

Usable load and moment

13. A general expression can be written for the axial load and moment in terms of C, and the location of the neutral axis, by using the stress-strain diagrams in Figure 4. The expressions for P_i and M_i are found by setting the sum of horizontal loads and moment equal to zero. Both conditions must be

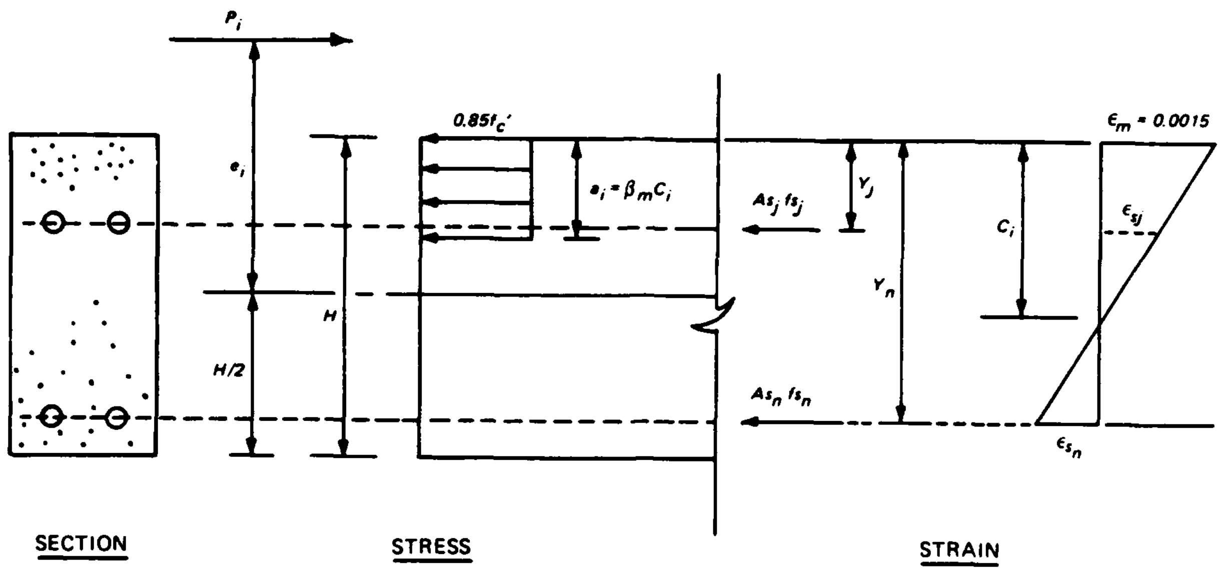


Figure 4. Programmed relationships for stress and strain

satisfied for equilibrium. Therefore, for any general value of C_i

$$P_i = 0.85f'_c\beta_m C_i b + \sum_{j=1}^{n} As_j fs_j$$

$$M_i = 0.85f'_c\beta_m C_i b \left(H - \frac{\beta_m C_i}{2.0}\right) - P_i \left(\frac{H}{2.0}\right) + \sum_{j=1}^{n} As_j fs_j (H - Y_j)$$

where n equal number of layers of steel. An expression for the stress in each layer of steel in terms of C_i can be developed from the strain diagram

$$fs_j = (C_i\varepsilon_m - \varepsilon_m Y_j/C_i)E_s \qquad -f_y \leq f_{sj} \leq f_y$$

14. The general expressions for P_i and M_i shown in the preceding paragraph can generate an interaction diagram by iterating the value of C from near zero to near infinity and computing the values of P_i and M_i for each value of C_i. This, in effect, computes the full range of load and moment capacities of the section with all possible positions of the neutral axis.

Ductility

15. The ACI Code requires that the steel ratio cannot exceed $0.75\rho_b$ for members with axial load less than $0.10f'_c bh$. During the design process of the program, if the tension steel required exceeds limitations on steel ratios, compression steel must be added. This addition of a sufficient amount of compression steel is made so that the portion of tension steel resisted by concrete compressive stresses does not exceed the specified upper limits on steel ratio (paragraph 10.3.3, ACI Code 318-83). For convenience, CASTR computes and prints the minimum size beam depth which can be used without compression steel. Columns are designed without regard for ductility.

Iterating to a solution

16. Paragraph 13 describes how an interaction diagram can be generated for a given problem. CASTR designs begin with a very small amount of steel and generates an interaction diagram. If the loading falls outside the envelope created by the diagram, steel areas are increased and a new diagram is generated. This process continues until the diagram exceeds loadings and, in the case of beams, until steel ratio limits are satisfied.

Data File Preparation--Complete Description

17. The data file must be prepared in advance by using line numbers with three digits. One blank space must follow the line number; data values should be separated by one or more blanks. Lines may not be continued. Units are kips and inches, except that applied moments (RMU) are in kip-feet. Appendix D contains a summary of the information in this paragraph.

Fixed data

18. The first four lines of the data file may be thought of as fixed data since these lines are used only once in a data file.

a. Job title. Two lines of job title must be first in the file. Each of the two lines must have a line number, a blank space, and up to 30 characters of job title.

b. Mode line.

LN MODE

where

LN = Line Number

MODE = 1 for investigation (paragraph 7)
2 for column design (paragraph 5)
3 for beam design (paragraph 4)

c. Properties line.

LN FC FY PEROB

where

LN = Line Number

FC = concrete ultimate strength f'_c , ksi

FY = steel yield strength f_y , ksi

PEROB = limiting ratio of actual reinforcement to balance reinforcement. Use only when MODE = 1 (investigation) or 3 (beam design). It must be omitted when MODE = 2 . Usual values are 0.75 except for Corps of Engineers conduits with large axial force where 0.375 is used.

Section data

19. Section data sets may be repeated without limit, in order to examine as many sections as desired.

a. Section title line. One line, with a line number, one blank space, then up to 30 characters of section and/or load case title.

b. Geometry line.

LN B H

where

LN = Line Number

B = section width, in.

H = section total height, in.

c. Reinforcing lines. Refer to Figure 5 for reinforcement descriptions of investigation problems and column design; refer to Figure 6 for beam design.

(1) If MODE = 1 for investigation or 2 for column design.

(a) LN NLAY

where

LN = Line Number

NLAY = number of layers of steel, may be zero

(b) (Use this line if NLAY is greater than zero, repeat the line NLAY times):

LN NBAR(I) ABAR(I) AY(I) XX1(I) XX2(I)

where

LN = Line Number

NBAR = number of bars in layer I

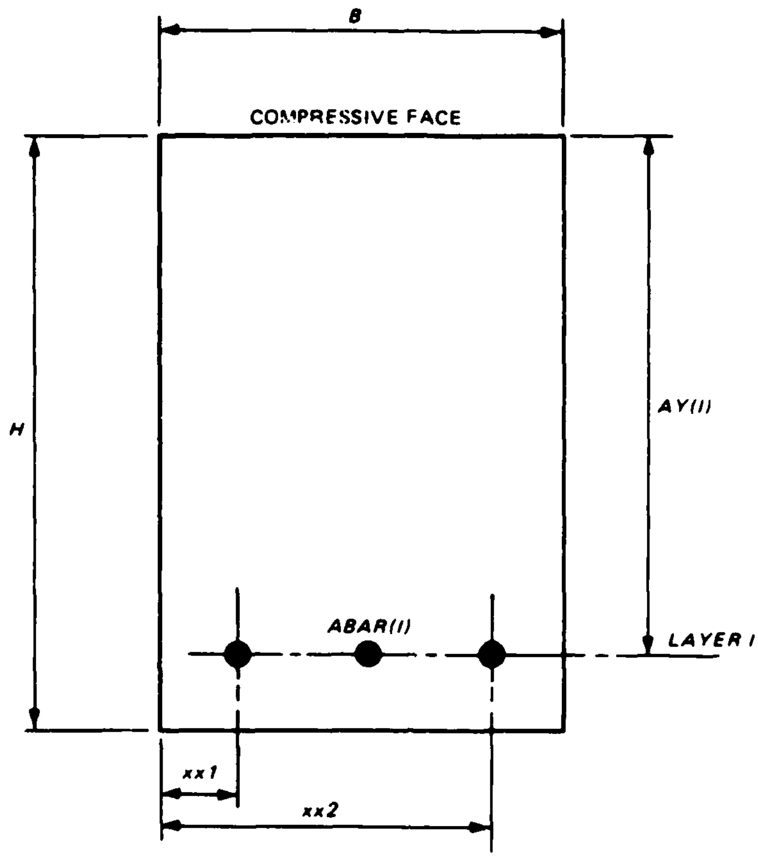


Figure 5. Investigation and column design variables

ABAR = area of one bar in layer I, in.^{2} for investigation. Minimum area of one bar in layer I for column design

AY = Y distance from compressive face to center of layer I, in.

XX1 = X distance from left side to center of leftmost end bar of layer I, in.

XX2 = X distance from left side to center of rightmost end bar in layer, in.

(2) If MODE = 3 for beam design:

(a) LN NCOM ACOM YCOM X1COM X2COM SCLAY

where

LN = Line Number

NCOM = number of bars per compressive layer

ACOM = maximum area allowed for one bar in a compressive layer, in.^{2}

YCOM = Y distance from compressive face to the center of the outermost (top) layer, in.

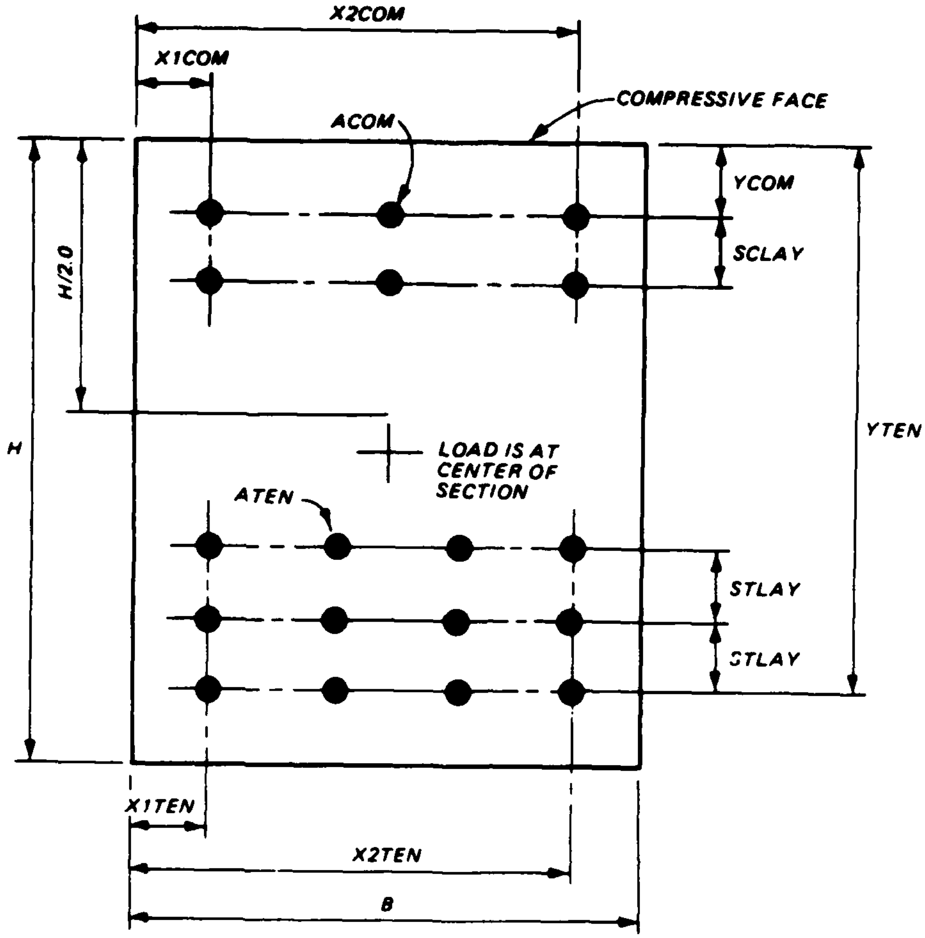


Figure 6. Beam design variables

X1COM = X distance from left side to the center of the leftmost end bar in a layer of compressive steel, in.

X2COM = X distance from the left side to the center of the rightmost end bar in a layer of compressive steel, in.

SCLAY = center-to-center spacing (Y-direction) between layers of compressive steel, in.

(b) LN NTEN ATEN YTEN X1TEN X2TEN STLAY

where these tensile steel descriptions are similar to the corresponding descriptions for compressive steel in subparagraph (a) on preceding page.

d. Load line.

LN PU RMU

where

LN = Line Number

PU = factored axial load, kips, located at B/2 , H/2 , compression +

RMU = factored bending moment, kip-feet, including the moment induced by PU not actually located at H/2 . Always entered as a positive value, tending to cause compression in the face so considered when defining the reinforcing steel. Remember the code requirements for minimum moment when the theoretical moment is zero.

Running the Program

20. The following information is a step-by-step guide for preparing a data file and program operation.

a. Begin the program:

(1) Honeywell computers: (* prompt)

*FRN WESLIB/CORPS/X0066,R

(2) CDC computers: (/ prompt)

/OLD,CORPS/UN=CECELB

/BEGIN,,CORPS,X0066

(3) Harris computers: (no prompt)

*CORPS,X0066

b. Enter the data file name when requested. This must be in all capital letters for the microcomputer version.

c. When the bell sounds, the program will pause for the user to make hard copies or notes of what is currently displayed, then press the "RETURN" key to continue.

d. The message "END OF DATA" indicates that all of the data have been processed without file read errors. Refer to paragraph 25 for an explanation of error messages.

Interpretation of Output

21. Output interpretation and investigation following a program is as vital to its success as the preliminaries for the actual run.

Investigation (MODE = 1)

22. Beginning with this paragraph and through paragraph 24, the designation of "figure" applies to computer output Figures 1 and 2.

a. Figure 1 includes tables of basic data and a picture of the section. The analysis parameters β_m , ε_{max} , f_c/f'_c , ϕ_{axial} , and $\phi_{flexure}$ are listed.

b. Figure 2:

(1) Two P/M interaction curves, one with the capacity reduction factor PHI included ("DESIGN STRENGTH") and one without ("NOMINAL STRENGTH"). The nominal strength curve is annotated with the axial force strength upper limit value. The balance point is indicated with an *.

(2) PU, RMU, and the PHI factor used for the given loading.

(3) Pass/fail message relating to the ability of the section to resist the applied PU and RMU, with PHI included. The admissible range is assumed to be within the "DESIGN STRENGTH" curve, without regard for ductility requirement PEROB. Ductility satisfaction or failure is reported by a message.

(4) The percentage of permissible design strength used by the factored applied loading is reported in a message, along with a message describing the type of failure expected at the given eccentricity.

Column design (MODE = 2)

23. Column design is composed of two figures as described below.

a. Figure 1: Tables of basic data and picture of final section as designed. The bar areas in the table of "Reinforcement Areas and Positions" are as designed, not the minimum values in the data input. Analysis parameters used are listed.

b. Figure 2: Same as for investigation, plus the minimum effective depth required with the input value of B to yield an acceptable section without compressive reinforcement.

Beam design (MODE = 3)

24. Beam design, as in column design, is shown by figures made up of data tables as listed:

a. Figure 1: Tables of basic data and picture of final section as designed. The bar areas in the table of "Reinforcement Areas and Positions" are as designed and not the limiting values in the data file. Gross steel ratios for tensile and for compressive steel are listed.

b. Figure 2: Same as for Column Design except that a message on the right side of the figure shows compliance with ductility requirement PEROB.

Error Messages

25. Listed below are possible error messages and a brief explanation of each one:

a. The message "### DATA ERROR ### LAST LINE WAS nnn" means one of several things:

(1) Improper value for MODE, in which case nnn will be the line number of the MODE line in the data file.

(2) Incomplete data file, one item or an entire line missing, in which case nnn will be the number of the last line in the file.

(3) A decimal point used after a data item name beginning with the letters M or N, in which case nnn will be the number of the line containing the improper decimal point.

(4) A misplaced Job Name or Section Name line, in which case nnn will be the number of the misplaced Name line.

b. If MODE = 2 for column design, a message "A REINF. DESIGN CANNOT BE FOUND--COLUMN SIZE MUST BE INCREASED" means that the bar size needed exceeded 100 in.^{2}*

c. If MODE = 3 for ductile beam design, a message "A REINF. DESIGN CANNOT BE FOUND--EITHER BEAM SIZE OR BAR SIZE MUST BE INCREASED" means that so many layers of reinforcing containing bars of the specified quantity and maximum size were needed that the tensile and compressive reinforcing patterns overlapped.

Special Uses of Program

26. The program is versatile in its uses and specific areas are described in the following paragraphs. Call the authors for information on advanced research capabilities.

Slab design

27. Slabs may be designed by inputting a 12.0-in.-wide strip.

Unreinforced section

28. An unreinforced section can be analyzed by inputting NLAY = 0 in the reinforcement data and omitting bar descriptions.

Nonductile beam design

29. If the user wants to design a beam forcing the design to be singly reinforced without regard for ductility, the column design procedure can be used. Reinforcement can be described as layers only in the tensile face.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Sample Problems

30. A sample investigation problem is presented in Appendix A, a sample column design problem is presented in Appendix B, and a sample beam problem is presented in Appendix C. An abbreviated description of a data file preparation is included in Appendix D.

Verification

31. The parent program, X0066, was checked thoroughly with hand computations. Since the only differences between X0066 and X0067 are as shown below, and since these differences were also verified during the preparation of program X0066, no additional verification is needed for Program X0067. These differences are shown in the following tabulation.

	β	ε_{max}	Nominal Axial Force Strength Factor Limit
X0066 (CSTR)	$f'_c \le 4.0$, $\beta^*_m = 0.55$	0.0015	0.7
	$f'_c > 4.0$, $\beta_m = 0.5$		
X0067 (CASTR)	$f'_c \le 4.0$, $\beta^*_m = 0.85$		
	$f'_c > 4.0$: $\beta_1 = \beta_1 - 0.05\ (f'_c - 4.0)$ but $\beta_1 \ge 0.65$	0.003	0.8

Note: β_m in program X0066 (CSTR) is equivalent to β_1 in program X0067 (CASTR).

Appendix A: Sample Investigation Program

Problem description

Fixed data:

$f'_c = 3.0$ ksi, $f_y = 40.0$ ksi

Section 1:

3 bars @ 0.95 $\boxed{''}$/bar

$P_u = 42.0$ kips

$M_u = 157.0$ k-ft

Section 2 (Appendix C design):

Top reinforcement

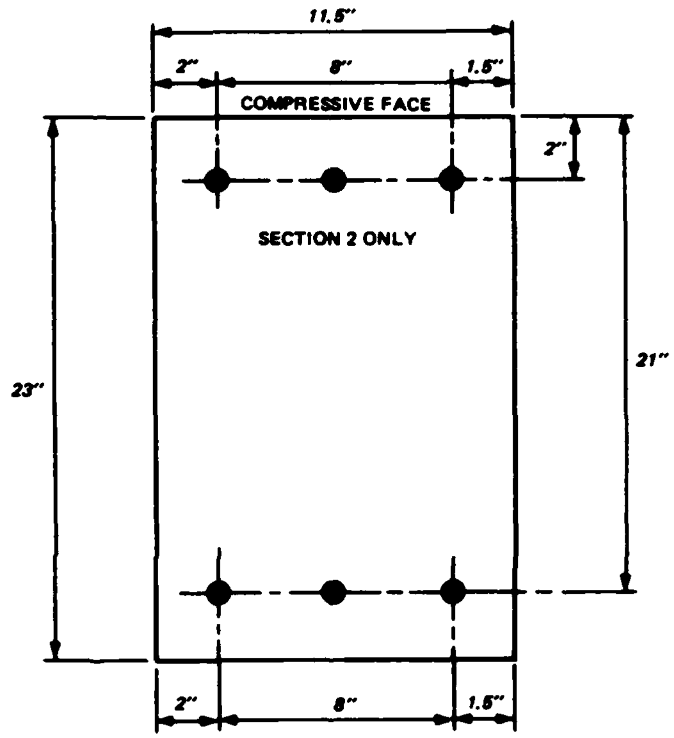
3 bars @ 0.29 $\boxed{''}$/bar

Bottom reinforcement

3 bars @ 0.92 $\boxed{''}$/bar

$P_u = 46.0$ kips

$M_u = 170.0$ k-ft



Computer run

```
                                                  *INVDA
*LIST INVDA

100 PROGRAM X0067 DEMO
110 INVESTIGATION
200 1
210 3 0  40.0  0.375
300 11.5 X 23 WITH 1 LAYER
400 11.5  23.0
500 1
510 3  0.95  21.0  2.0  10.0
600 42.0  157.0
700 Appendix C problem
710 11.5  23.0
720 2
730 3  0 29   2.0  2 0  10.0
740 3  0 92  21.0  2 0  10.0
750 46.0  170.0


*FRN WESLIB/CORPS/X0067.R
******************************
*  CORPS PROGRAM  #  X0067   *
*        VERSION  # 86/06/17 *
******************************

 THE BELL WILL RING AT EACH PAUSE FOR YOU TO COPY
 WHAT YOU WANT. THEN PRESS 'RETURN' TO CONTINUE.


PROGRAM X0067 -- CASTR -- 713-F3-R0 067
CONCRETE STRENGTH INVESTIGATION & DESIGN
IN ACCORDANCE WITH ACI CODE 318-83
REV 0.4 -- JUNE 1986


ENTER NAME OF DATA FILE
```

PROGRAM X0067 -- CASTR -- 713-F3-R0 067
CONCRETE STRENGTH INVESTIGATION & DESIGN

DIMENSIONS OF CONCRETE SECTION

WIDTH(B) INCHES	HEIGHT(H) INCHES
11.500	23.000

REINFORCEMENT AREAS AND POSITIONS

LAYER NO.	NO. BARS	AREA BAR	Y (IN.)	X1 (IN.)	X2 (IN.)
1	3	0.85	21.00	2.00	10.00

MATERIAL CONSTANTS

F'C = 3.000 KSI
FY = 40.000 KSI

FACTOR p/p-bal. PEROB = 0.375

ANALYSIS FOLLOWS ACI CODE 318-83:
STRESS BLOCK DEPTH RATIO, BR = 0.850
MAXIMUM CONCRETE STRAIN, EMAX = 0.003000
CONCRETE STRESS RATIO fc/f'c, FCR = 0.8500
PHI FOR FLEXURE, PHIF = 0.900
PHI FOR AXIAL LOAD, PHIA = 0.700

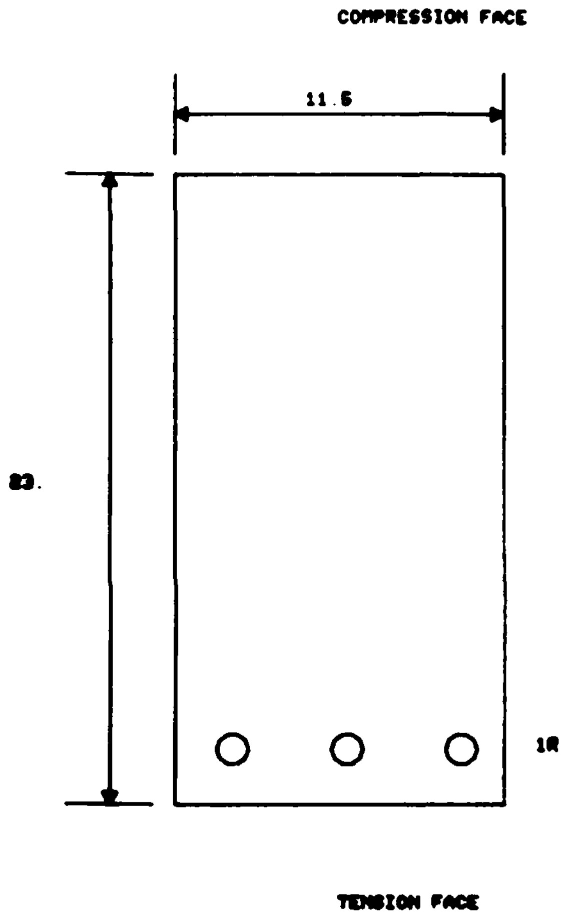


Figure 1. BASIC DATA SUMMARY

PROGRAM X0067 DEMO
INVESTIGATION
11.5 X 23 WITH 1 LAYER

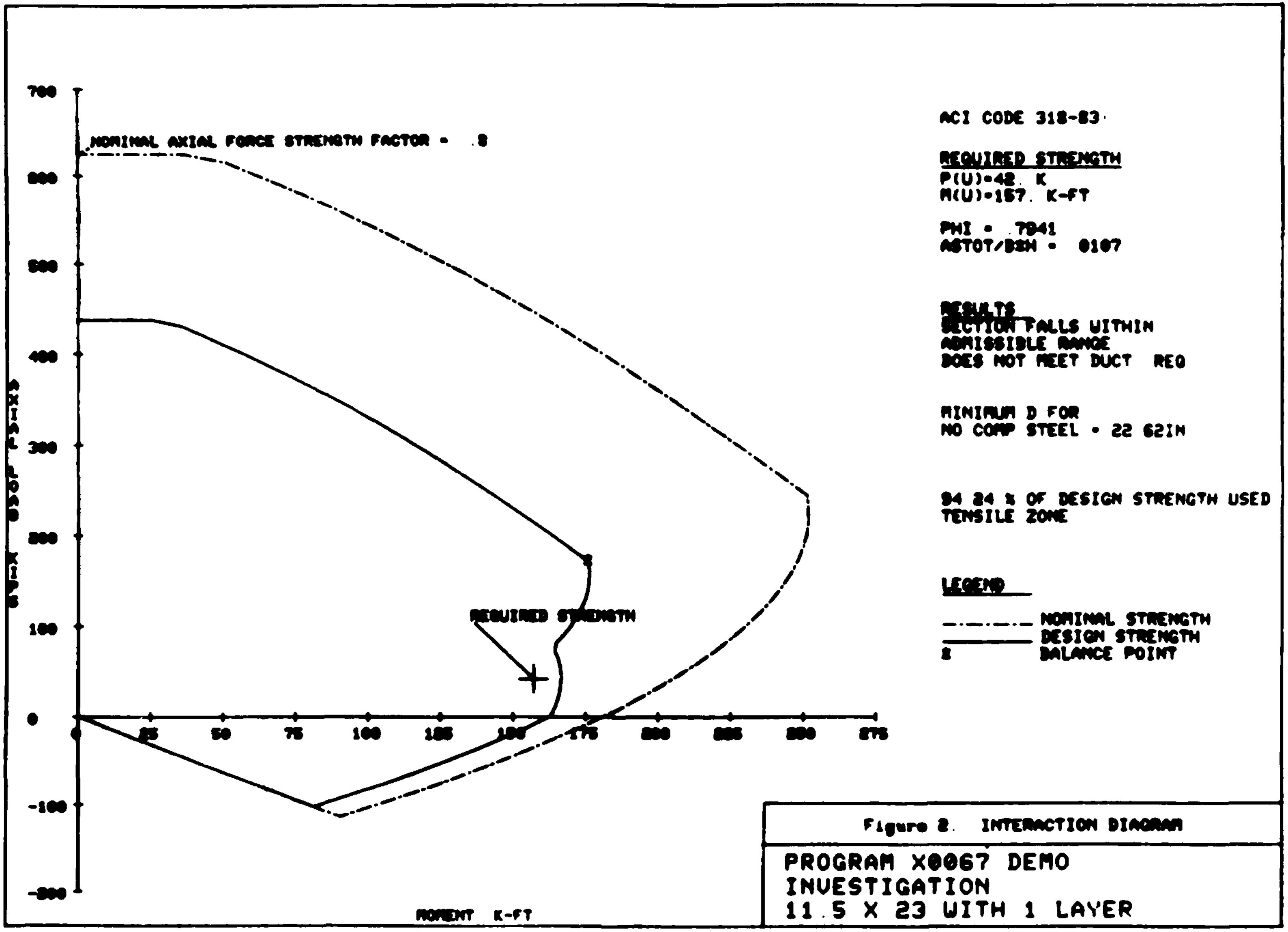


Figure 2. INTERACTION DIAGRAM

```
PROGRAM X0067 -- CASTR -- 713-F3-R0 067
CONCRETE STRENGTH INVESTIGATION & DESIGN

DIMENSIONS OF CONCRETE SECTION
------------------------------
WIDTH(B)          HEIGHT(H)
INCHES            INCHES
  11.500            23.000

REINFORCEMENT AREAS AND POSITIONS
---------------------------------
LAYER   NO.    AREA     Y       X1      X2
NO      BARS   BAR    (IN.)   (IN.)   (IN.)
  1       3    0.20    2.00    2.00   10.00
  2       3    0.60   21.00    2.00   10.00

MATERIAL CONSTANTS
------------------
F'C =  3.000 KSI
FY = 40.000  KSI

FACTOR p/p-bal. PEROB = 0.376

ANALYSIS FOLLOWS ACI CODE 318-83:
   STRESS BLOCK DEPTH RATIO, BR = 0.850
   MAXIMUM CONCRETE STRAIN, EMAX = 0.003000
   CONCRETE STRESS RATIO fc/f'c, FCR = 0.8500
   PHI FOR FLEXURE, PHIF = 0.900
   PHI FOR AXIAL LOAD, PHIA = 0.700
```

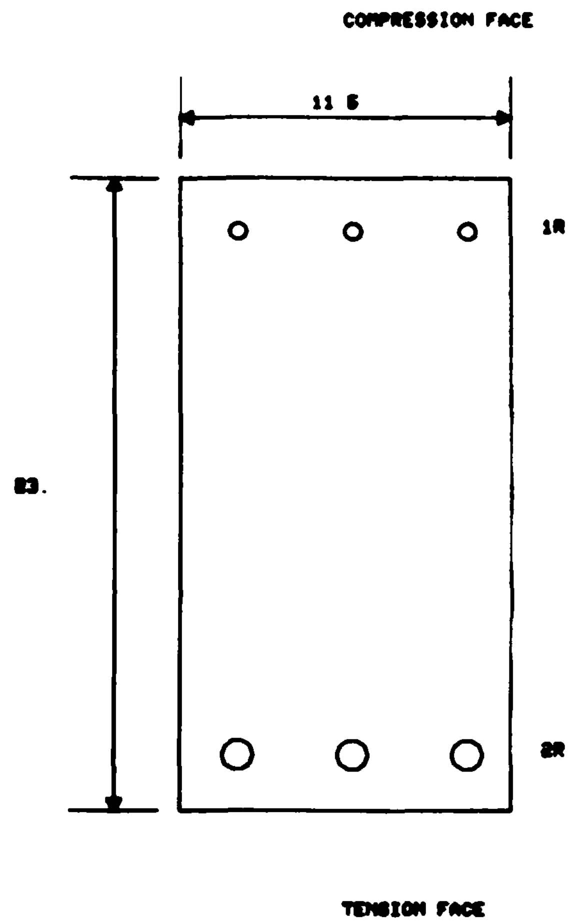


Figure 1. BASIC DATA SUMMARY

PROGRAM X0067 DEMO
INVESTIGATION
Appendix C problem

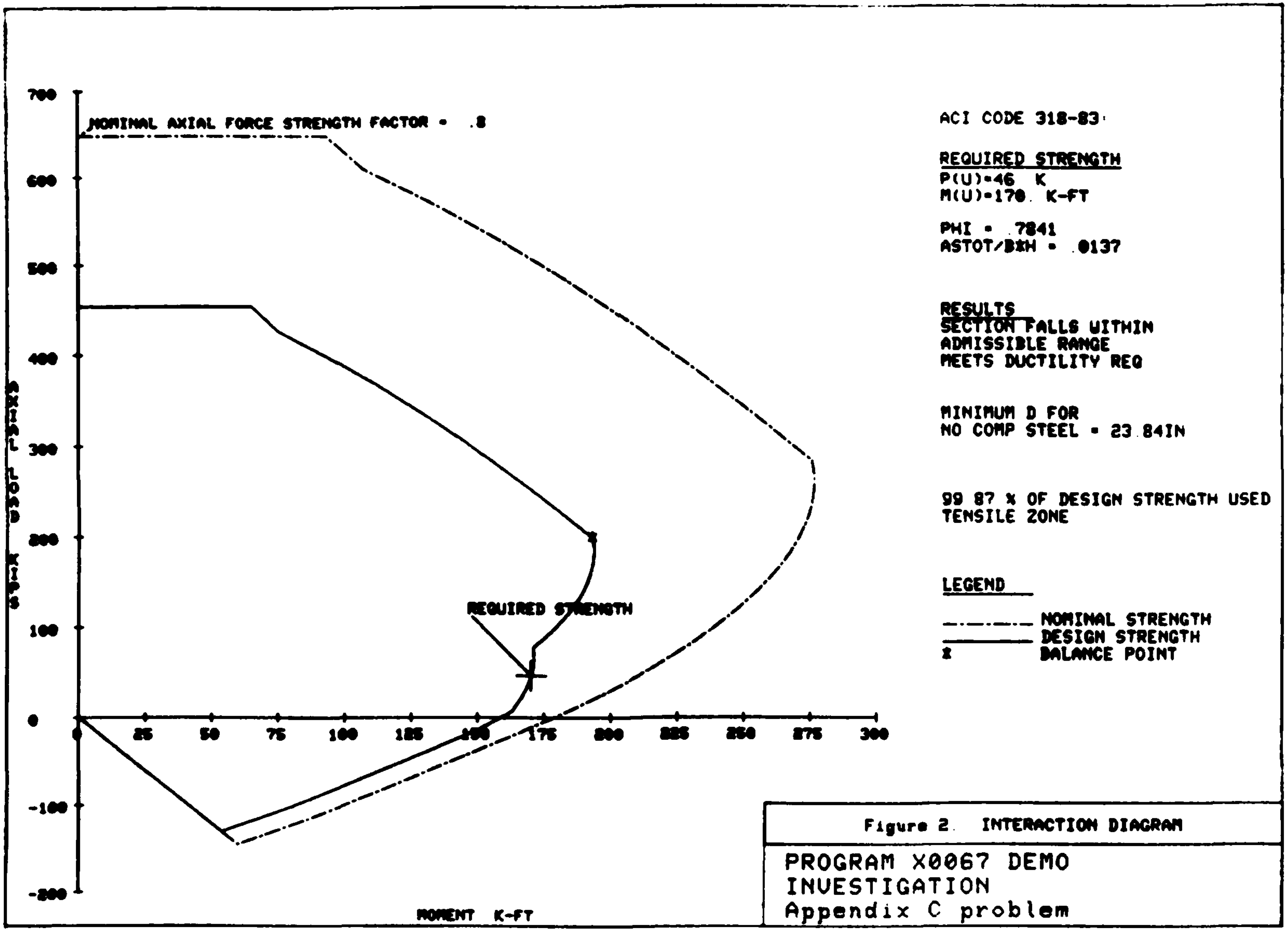


Figure 2. INTERACTION DIAGRAM

END OF DATA

*

Appendix B: Sample Column Design Problem

Problem description

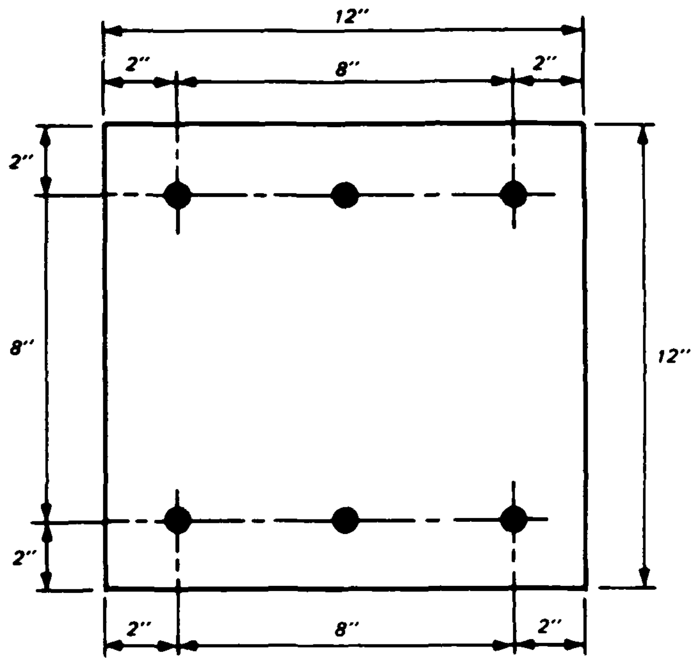
$f'_c = 3.0$ ksi

$f_y = 40.0$ ksi

6 bars @ 0.1 $\boxed{''}$ /bar, min.

$P_u = 50.0$ kips

$M_u = 50.0$ k-in.

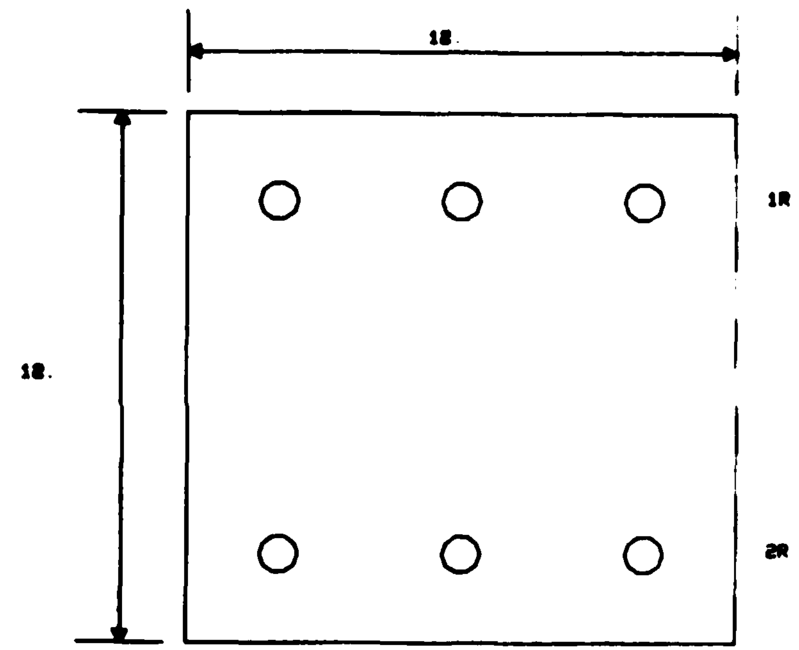


Computer run

```
*LIST COLDA

100 PROGRAM X0067 DEMO
110 COLUMN DESIGN
200 2
210 3.0  40.0
300 12 X 12
400 12.0  12.0
500 2
510 3  0.1   2.0  2.0  10.0
520 3  0.1  10.0  2.0  10.0
600 50.0  50.0

*FRN WESLIB/CORPS/X0067.R
******************************
*  CORPS PROGRAM  #  X0067   *
*        VERSION  # 86/06/17 *
******************************

 THE BELL WILL RING AT EACH PAUSE FOR YOU TO COPY
 WHAT YOU WANT, THEN PRESS "RETURN" TO CONTINUE.


PROGRAM X0067 -- CASTR -- 713-F3-R0 067
CONCRETE STRENGTH INVESTIGATION & DESIGN
IN ACCORDANCE WITH ACI CODE 318-83
REV 0.4 -- JUNE 1986

ENTER NAME OF DATA FILE
=COLDA
```

```
PROGRAM X0067 -- CASTR -- 713-F3-R0 067
CONCRETE STRENGTH INVESTIGATION & DESIGN

DIMENSIONS OF CONCRETE SECTION
------------------------------
WIDTH(B)          HEIGHT(H)
INCHES            INCHES
  12.000            12.000

REINFORCEMENT AREAS AND POSITIONS
---------------------------------
LAYER   NO.     AREA      Y        X1       X2
NO.     BARS    BAR     (IN.)    (IN.)    (IN.)
  1       3     0.55     2.00     2.00    10.00
  2       3     0.55    10.00     2.00    10.00

MATERIAL CONSTANTS
------------------
F'C =  3.000 KSI
FY = 40.000  KSI

ANALYSIS FOLLOWS ACI CODE 318-83.
   STRESS BLOCK DEPTH RATIO, BR = 0.850
   MAXIMUM CONCRETE STRAIN, EMAX = 0.003000
   CONCRETE STRESS RATIO fc/f'c, FCR = 0.8500
   PHI FOR FLEXURE, PHIF = 0.900
   PHI FOR AXIAL LOAD, PHIA = 0.700
```

COMPRESSION FACE



TENSION FACE

Figure 1. BASIC DATA SUMMARY

PROGRAM X0067 DEMO
COLUMN DESIGN
12 X 12

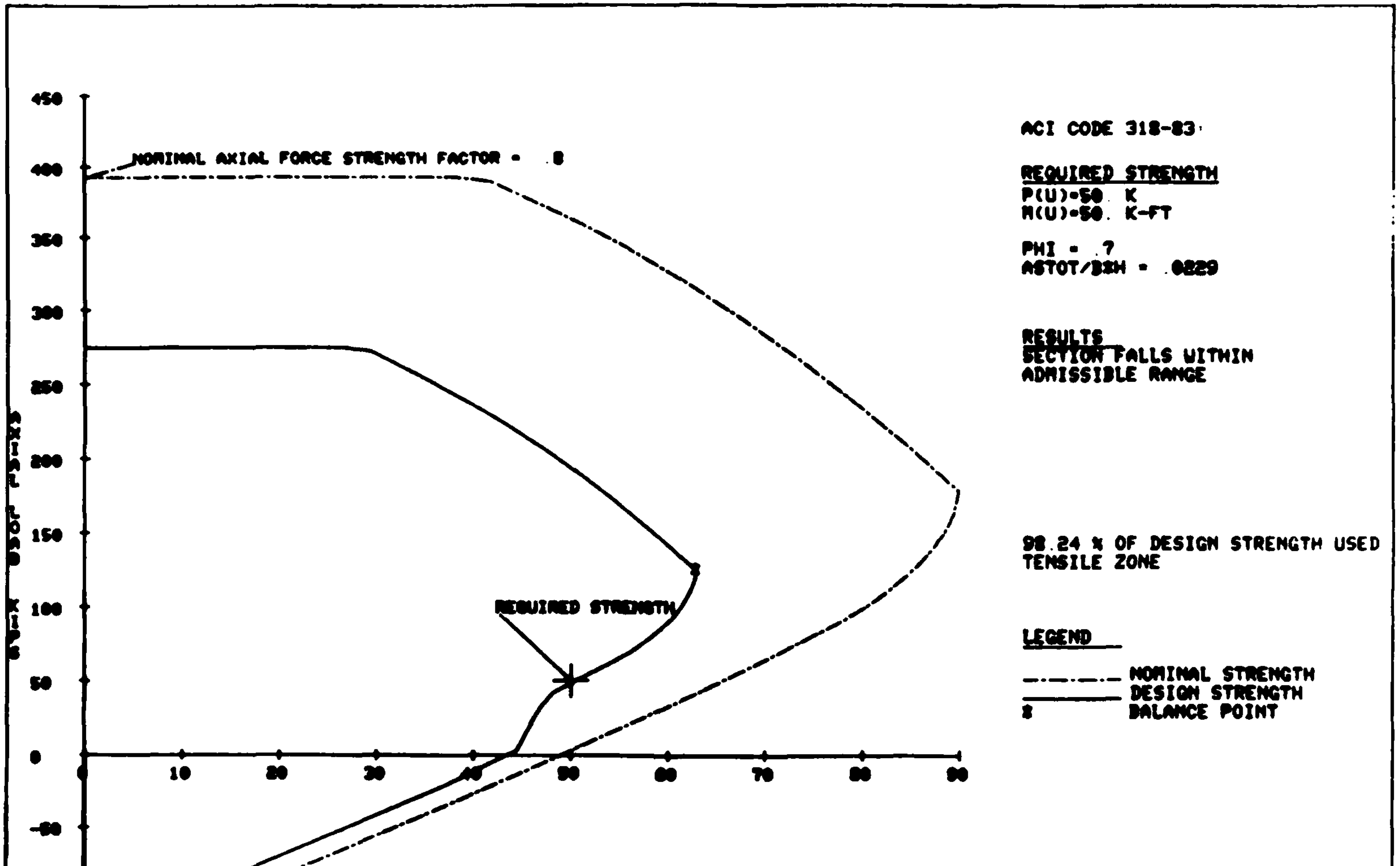


Figure 2. INTERACTION DIAGRAM

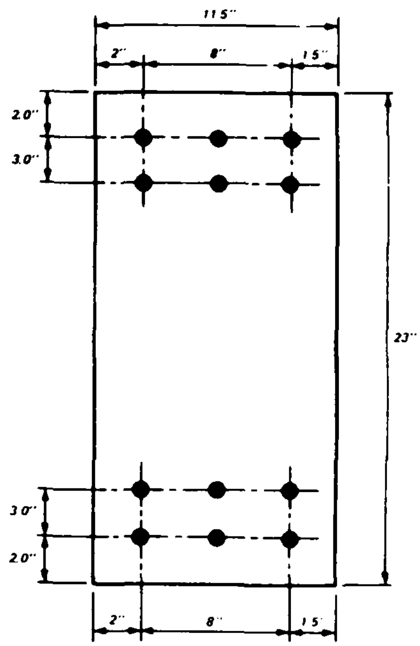
PROGRAM X0067 DEMO
COLUMN DESIGN
12 X 12

END OF DATA

*

Appendix C: Sample Ductile Beam Design Problem

Problem description



f'_c = 30.0 ksi

f_y = 40.0 ksi

$\frac{p}{p_{bal}}$ = 0.375 max

P_u = 46.0 kips

M_u = 170.0 k-in. load case 2

Compressive steel:

3 bars/layer

As_{max} = 5.0 $\boxed{''}$ /bar

Tensile steel:

3 bars/layer

As_{max} = 5.0 $\boxed{''}$ /bar

Validation: The design produced by this example is used as the data for the Section 2 problem in Appendix A.

Computer run

```
*LIST BEAMDA

100 PROGRAM X0067 DEMO
110 DUCTILE BEAM DESIGN
200 3
210 3.0   40.0   0.375
300 11.5 X 23 W/COMP ALLOWED
400 11.5   23.0
500 3   5.0    2.0   2.0   10.0   3.0
510 3   5.0   21.0   2.0   10.0   3.0
600 46.0   170.0

*FRN WESLIB/CORPS/X0067.R
******************************
*  CORPS PROGRAM  *  X0067    *
*         VERSION  * 86/06/17 *
******************************

 THE BELL WILL RING AT EACH PAUSE FOR YOU TO COPY
 WHAT YOU WANT, THEN PRESS 'RETURN' TO CONTINUE.


PROGRAM X0067 -- CASTR -- 713-F3-R0 067
CONCRETE STRENGTH INVESTIGATION & DESIGN
IN ACCORDANCE WITH ACI CODE 318-83
REV 0 4 -- JUNE 1986

ENTER NAME OF DATA FILE
*BEAMDA
```

PROGRAM X0067 -- CASTR -- 713-F3-R0 067
CONCRETE STRENGTH INVESTIGATION & DESIGN

DIMENSIONS OF CONCRETE SECTION

WIDTH(B)   HEIGHT(H)
INCHES   INCHES
11.500   23.000

REINFORCEMENT AREAS AND POSITIONS

LAYER NO.	NO. BARS	AREA BAR	Y (IN.)	X1 (IN.)	X2 (IN.)
1	3	0.20	2.00	2.00	10.00
2	3	0.[illegible]	21.00	2.00	10.00

MATERIAL CONSTANTS

F'C = 3.000 KSI
FY = 40.000 KSI

FACTOR p/p-bal. PEROB = 0.375

ANALYSIS FOLLOWS ACI CODE 318-83:
STRESS BLOCK DEPTH RATIO, BM = 0.850
MAXIMUM CONCRETE STRAIN, EMAX = 0.003000
CONCRETE STRESS RATIO fc/f'c, FCR = 0.8500
PHI FOR FLEXURE, PHIF = 0.900
PHI FOR AXIAL LOAD, PHIA = 0.700

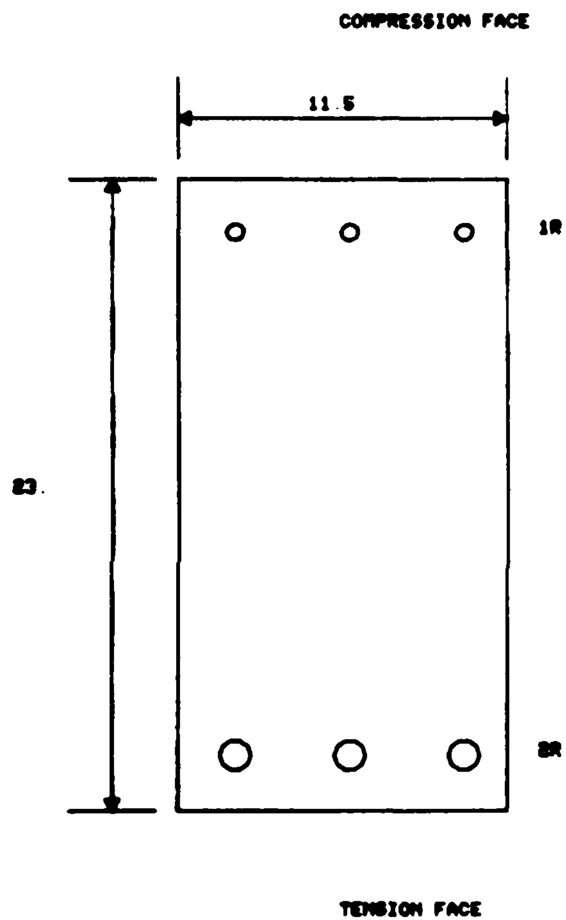
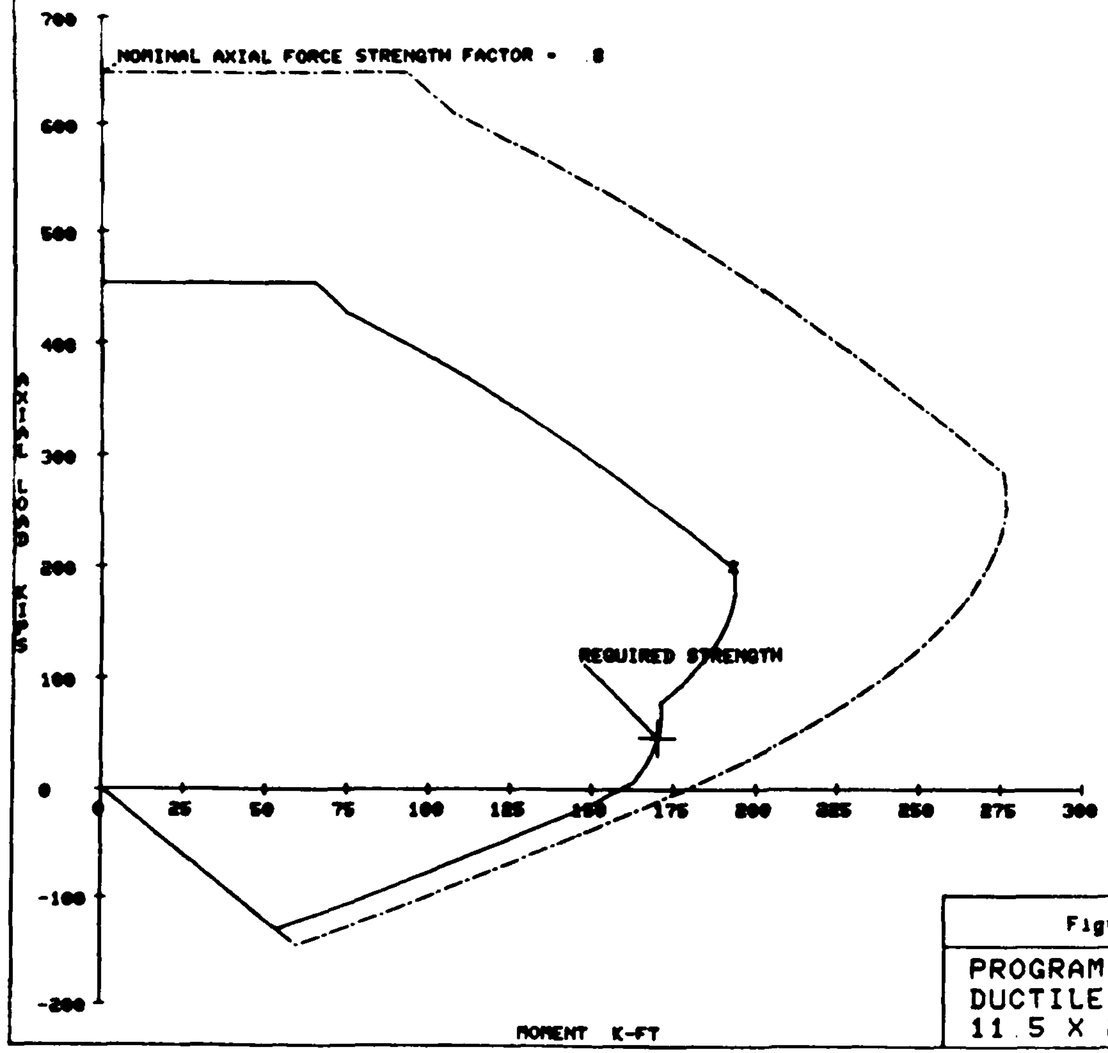


Figure 1. BASIC DATA SUMMARY

PROGRAM X0067 DEMO
DUCTILE BEAM DESIGN
11.5 X 23 W/COMP ALLOWED



ACI CODE 318-83

REQUIRED STRENGTH
P(U)=46 K
M(U)=170 K-FT

PHI = .7841
ASTOT/B*H = .0137

RESULTS
SECTION FALLS WITHIN
ADMISSIBLE RANGE
MEETS DUCTILITY REQ

MINIMUM D FOR
NO COMP STEEL = 23 84IN

99 87 % OF DESIGN STRENGTH USED
TENSILE ZONE

LEGEND

-.-.-.- NOMINAL STRENGTH
——— DESIGN STRENGTH
* BALANCE POINT

Figure 2 INTERACTION DIAGRAM

PROGRAM X0067 DEMO
DUCTILE BEAM DESIGN
11 5 X 23 W/COMP ALLOWED

END OF DATA

*

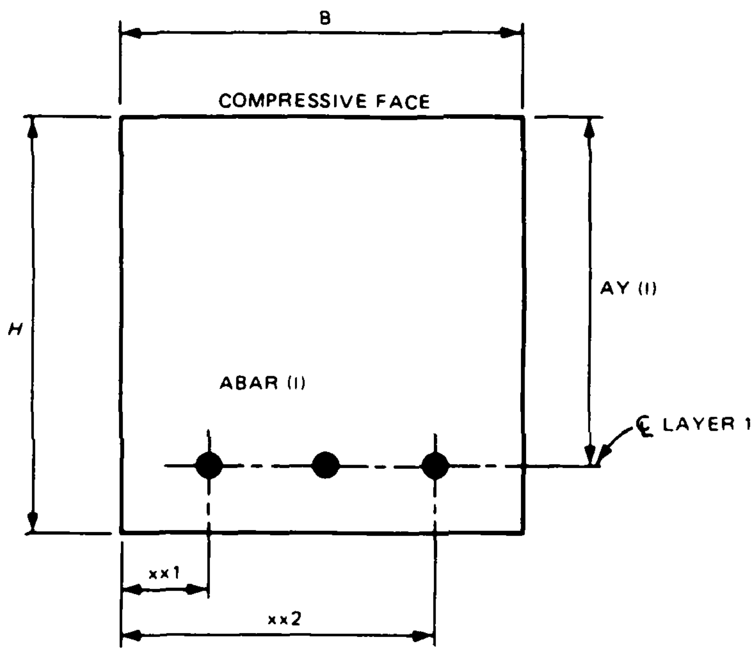
Appendix D: Abbreviated Data File Guide

Abbreviated description of data file preparation

1. This program will investigate or design. Paragraph 2 is concerned with investigation and design of columns, and Paragraph 3 deals with design of beams.

Investigation and column design (MODE = 1 or 2)

2.



Note: ABAR(I) = area of one bar in layer I for investigation or ABAR(I) = min area of one bar for column design

LN JOB TITLE (30 characters max)

LN JOB TITLE (30 characters max)

LN MODE

LN FC FY PEROB (omit PEROB for column design)

Repeat for each load case:

LN SECTION TITLE (30 characters max)

LN B H

LN NLAY

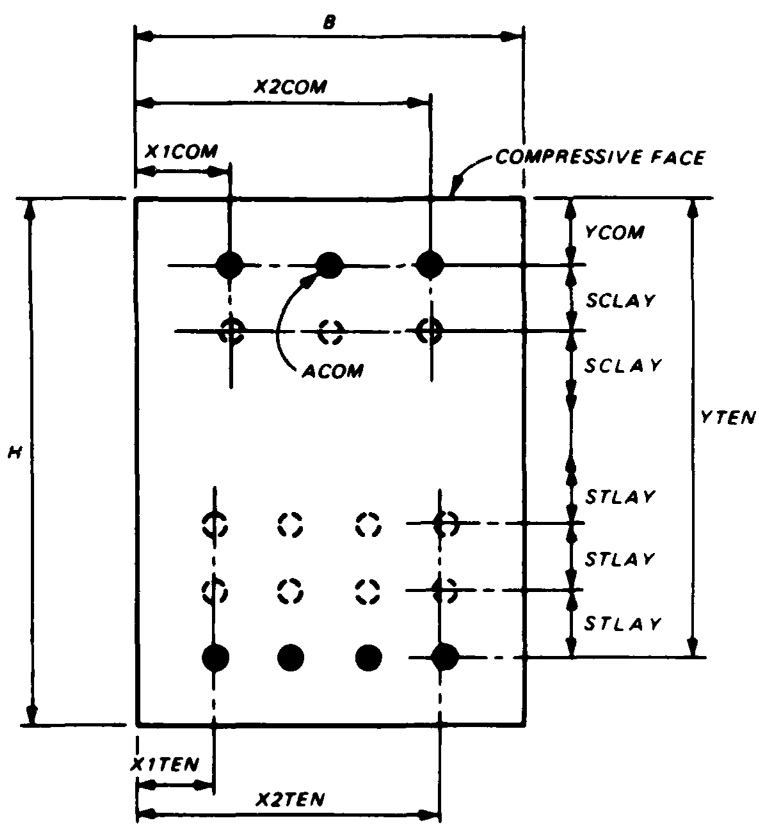
LN NBAR(I), ABAR(I), AY(I), XX1(I), XX2(I)

LN (repeat above line NLAY times, NLAY = number of layers)

LN PU, RMU

<u>Beam design</u>

3. (MODE = 3)



LN JOB TITLE (30 characters max)

LN JOB TITLE (30 characters max)

LN MODE

LN FC, FY, PEROB

Repeat for each load case	LN	SECTION TITLE (30 characters max)
	LN	B, H
	LN	NCOM, ACOM, YCOM, X1COM, X2COM, SCLAY
	LN	NTEN, ATEN, YTEN, X1TEN, X2TEN, STLAY
	LN	PU, RMU

Units

4. All dimensions are in inches, all areas are in square inches, and concrete and steel yield strengths are in kips per square inch. Forces are in kips at B/2 and H/2 ; compression is positive. Moments are in kip-feet and include the moment caused by the fact that the axial force is not at H/2 , and moments must be positive tending to cause compression in the top face in the diagram in paragraphs 2 and 3 of this appendix.

WATERWAYS EXPERIMENT STATION REPORTS PUBLISHED UNDER THE COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

	Title	Date
Technical Report K-78-1	List of Computer Programs for Computer-Aided Structural Engineering	Feb 1978
Instruction Report O-79-2	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Mar 1979
Technical Report K-80-1	Survey of Bridge-Oriented Design Software	Jan 1980
Technical Report K-80-2	Evaluation of Computer Programs for the Design/Analysis of Highway and Railway Bridges	Jan 1980
Instruction Report K-80-1	User's Guide: Computer Program for Design/Review of Curvilinear Conduits/Culverts (CURCON)	Feb 1980
Instruction Report K-80-3	A Three-Dimensional Finite Element Data Edit Program	Mar 1980
Instruction Report K-80-4	A Three-Dimensional Stability Analysis/Design Program (3DSAD)	
	Report 1: General Geometry Module	Jun 1980
	Report 3: General Analysis Module (CGAM)	Jun 1982
	Report 4: Special-Purpose Modules for Dams (CDAMS)	Aug 1983
Instruction Report K-80-6	Basic User's Guide: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Technical Report K-80-4	Documentation of Finite Element Analyses	
	Report 1: Longview Outlet Works Conduit	Dec 1980
	Report 2: Anchored Wall Monolith, Bay Springs Lock	Dec 1980
Technical Report K-80-5	Basic Pile Group Behavior	Dec 1980
Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CSHTWAL)	
	Report 1: Computational Processes	Feb 1981
	Report 2: Interactive Graphics Options	Mar 1981
Instruction Report K-81-3	Validation Report: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Feb 1981
Instruction Report K-81-4	User's Guide: Computer Program for Design and Analysis of Cast-in-Place Tunnel Linings (NEWTUN)	Mar 1981
Instruction Report K-81-6	User's Guide: Computer Program for Optimum Nonlinear Dynamic Design of Reinforced Concrete Slabs Under Blast Loading (CBARCS)	Mar 1981
Instruction Report K-81-7	User's Guide: Computer Program for Design or Investigation of Orthogonal Culverts (CORTCUL)	Mar 1981
Instruction Report K-81-9	User's Guide: Computer Program for Three-Dimensional Analysis of Building Systems (CTABS80)	Aug 1981
Technical Report K-81-2	Theoretical Basis for CTABS80: A Computer Program for Three-Dimensional Analysis of Building Systems	Sep 1981
Instruction Report K-82-6	User's Guide: Computer Program for Analysis of Beam-Column Structures with Nonlinear Supports (CBEAMC)	Jun 1982
Instruction Report K-82-7	User's Guide: Computer Program for Bearing Capacity Analysis of Shallow Foundations (CBEAR)	Jun 1982

(Continued)

WATERWAYS EXPERIMENT STATION REPORTS PUBLISHED UNDER THE COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

(Concluded)

	Title	Date
Instruction Report K-83-1	User's Guide: Computer Program With Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Jan 1983
Instruction Report K-83-2	User's Guide: Computer Program for Generation of Engineering Geometry (SKETCH)	Jun 1983
Instruction Report K-83-5	User's Guide: Computer Program to Calculate Shear, Moment, and Thrust (CSMT) from Stress Results of a Two-Dimensional Finite Element Analysis	Jul 1983
Technical Report K-83-1	Basic Pile Group Behavior	Sep 1983
Technical Report K-83-3	Reference Manual: Computer Graphics Program for Generation of Engineering Geometry (SKETCH)	Sep 1983
Technical Report K-83-4	Case Study of Six Major General-Purpose Finite Element Programs	Oct 1983
Instruction Report K-84-2	User's Guide: Computer Program for Optimum Dynamic Design of Nonlinear Metal Plates Under Blast Loading (CSDOOR)	Jan 1984
Instruction Report K-84-7	User's Guide: Computer Program for Determining Induced Stresses and Consolidation Settlements (CSETT)	Aug 1984
Instruction Report K-84-8	Seepage Analysis of Confined Flow Problems by the Method of Fragments (CFRAG)	Sep 1984
Instruction Report K-84-11	User's Guide for Computer Program CGFAG, Concrete General Flexure Analysis with Graphics	Sep 1984
Technical Report K-84-3	Computer-Aided Drafting and Design for Corps Structural Engineers	Oct 1984
Technical Report ATC-86-5	Decision Logic Table Formulation of ACI 318-77, Building Code Requirements for Reinforced Concrete for Automated Constraint Processing, Volumes I and II	Jun 1986
Technical Report ITL-87-2	A Case Committee Study of Finite Element Analysis of Concrete Flat Slabs	Jan 1987
Instruction Report ITL-87-1	User's Guide: Computer Program for Two-Dimensional Analysis of U-Frame Structures (CUFRAM)	Apr 1987
Instruction Report ITL-87-2	User's Guide: For Concrete Strength Investigation and Design (CASTR) in Accordance with ACI 318-83	May 1987
Technical Report ITL-87-6	Finite-Element Method Package for Solving Steady-State Seepage Problems	May 1987

END
9-87
DTIC